Everything you always wanted to know about fuzzy logic

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What is fuzzy logic?

Fuzzy logic is a mathematical discipline, based on fuzzy set theory, that allows for degrees of ... and falseness. It's a generalization of bilevel logic, ... holds that an assertion must be either true or ... and cannot partly true and partly false. In fuzzy ... a statement such as "Donald is short" can be 25% ... and 75% false if Donald is, say, 5 ft, 7 in. tall.

Can fuzzy logic be used in engineering design and, if so, how?

Yes, fuzzy logic can be and is currently being used in engineering design. One way engineers ... fuzzy logic is to describe the operation of a system ... of fuzzy variables and terms. An example ... fuzzy term is "fast," when referring to a car's ... a fuzzy variable. Other fuzzy terms that could ... for the fuzzy variable speed are "very slow," ... "medium fast," and "very fast."

...ntly, fuzzy logic is most often used in a rule ... borrowed from expert systems. The rules ... system operation and are stated in fuzzy—or ...—terms, for example:

... is fast and distance_to_stop is medium_long, ... accelerator is near_zero and brake is light.

...ion of these rules defines a system's operation ...ying outputs as functions of system inputs.

... would anyone want to design a system ... way?

A Because the operation of many systems is so complex that you cannot adequately define it using traditional techniques. Systems especially difficult to develop traditionally are those having nonlinearities or uncertainties.

Q **How did fuzzy logic come about?**

A The realization that systems were getting so horribly complex that accurate analytic models would be impossible to develop was becoming increasingly evident to researchers in the mid 1960s. Rather than throwing his hands up in despair, Lotfi Zadeh, professor of electrical engineering at the University of California at Berkeley, created fuzzy set theory as the cornerstone of a "soft" approach to system definition and design.

Q **Isn't fuzzy set theory just another way of looking at probability?**

A Critics often make this claim, and the answer is no. Probability theory is based on the measurement of random events; fuzzy set theory and fuzzy logic represent how strongly an element belongs to a given set.

James Bezdek, professor at the University of West Florida, suggests a scenario to clarify this difference. Suppose you've been lost in the desert for several days without water and you come upon two 1-gallon glass jars. One is marked to indicate that the probability it contains pure water is 0.91. The other is marked that the degree of membership (a fuzzy measure) of the contents in the class "pure water" is 0.91. Which would you drink? The first, with a 0.91 probability of being

pure water stands a 9% chance of being some other clear liquid—turpentine, for example. The second, which has a degree of membership in the set "pure water," could be clear swamp water—not the most desirable drink, but worth drinking in a pinch.

The difference becomes even clearer by considering what happens after observation. Suppose you happen to have a back-pocket chemical-analysis kit, and you determine that the liquid with 0.91 probability of being pure water is pure water and that the other liquid is lake water. The contents of both jars are now both known with 100% certainty (probability = 1.0), but the liquid in the second jar still has 0.91 membership in the class "pure water."

Q Does the fact that fuzzy logic allows for a continuous transition between truth and falseness make it similar to analog electronics?

A You can implement fuzzy-logic systems with analog hardware, and some analog chip houses are considering doing just that. But the fast, inexpensive, and sometimes dedicated-function (such as DSP) processors available today handle analog signals better using digital techniques.

Q Discounting the fuzzy critics, why is there such skepticism in the United States about using fuzzy logic?

A This skepticism at least partially stems from the distrust of new technology that people perceive as revolutionary. Some pundits suggest that people are skeptical of fuzzy logic because its name is perceived as silly. Others feel fuzzy logic has been too closely tied to artificial intelligence (AI), which many view as not having lived up to its early promise.

Q You brought it up: Is fuzzy logic akin to artificial intelligence?

A The currently dominant fuzzy-system architecture has its roots in expert systems, so you can consider that architecture a derivative of an AI technique.

I come to fuzzy systems with a background in real-time embedded systems. Professor Zadeh originally devised fuzzy logic while investigating extremely complex systems. Many AI researchers are interested in fuzzy logic and are using it in artificial-intelligence research, but engineers are also using the technology in "roll up your sleeves" industrial control. Remember, fuzzy logic is a mathematical foundation that has application in many disciplines.

Q Are fuzzy logic and neural nets related?

A Neural nets are inherently fuzzy, but fuzzy rule-based systems have no real neural structure. Fuzzy systems are not learning systems like neural networks; the "knowledge" they contain is put there by domain experts. But fuzzy logic and neural nets can be complementary. An example would be a neural net working—either in real time or off-line—to optimize the parameters of a fuzzy-logic system.

Q Let's get into less philosophical, more down to earth questions: When can I use fuzzy logic?

A Fuzzy logic finds its strongest application in complex systems that contain nonlinearities in their operation or have uncertainty either in their inputs or their operational description. Professor Zadeh says fuzzy logic is best for modeling or controlling huge natural systems—such as the weather, natural sciences, or the oceans—or huge man-made systems—such as the economy, the stock market, or nation elections. The success of using fuzzy logic to develop control systems surprised him. But even in control applications, fuzzy logic is best for

- systems too complex for you to accurately model
- systems with moderate to significant operational nonlinearities
- systems having uncertainties in either their inputs or definition.

Q When should I avoid using fuzzy logic?

A Stick with traditional methods for systems for which conventional control equations and methods are already optimal or entirely adequate.

However, when a current solution is adequate and a fuzzy solution is better or much better or opens significant new and desirable possibilities, don't ignore the fuzzy replacement. Think of the number of "adequate" systems that early microprocessors replaced and how system capabilities have been expanded through their use. Now, the decision is not whether to use a microprocessor but, rather, what functions it will perform and what functions will be performed by peripheral circuits. Without wanting to blow the trumpet too loudly, fuzzy logic has the potential to impact technology as significantly as the microprocessor.

Q Is fuzzy logic limited to the consumer applications so evident in Japan?

A Definitely not. In addition to highly visible consumer applications, the Japanese are using fuzzy logic in industrial and critical control. Hitachi has developed a fuzzy-control system for the Sendai subway system, and all the Japanese car makers are heavily involved in using fuzzy logic for antilock brakes, engine control, transmission control, and active suspensions.

Q How does fuzzy system development compare with traditional system development?

A This question is difficult to answer in quantitative terms because the Japanese have provided only qualitative answers. But having collected these answers and talked with engineers experienced in both traditional and fuzzy system design, I've devised these vague rules of thumb:

- For a control system that can use either a linear or fuzzy approach, fuzzy systems tend to go together two to four times more easily. Some engineers quote a factor of 10, but I tend to be more conservative.
- Using the same standard microprocessor, a fuzzy software implementation will take approximately half the memory as a linear one.

  Be cautious with this number. It assumes what is, in effect, an interpreted fuzzy solution, which will take less memory and run slower than its compiled equivalent. My own experience is that when a fuzzy system is optimized for speed, memory size is comparable with that of a traditional system.
- Because you design fuzzy systems "intuitively" using linguistic terms, the basics of fuzzy system design are far easier to learn than, for example, those of linear design using root-locus or state-space methods. However, as with any technique, you'll learn the hidden "gotchas" with experience. An example is the ease of "fuzzy hacking" when using a simulator. With an analytic system, you always have the system model to fall back on when attempting to perform fine tuning. A fuzzy system has only the designer's experience, and hacking is typically easier, although definitely not the best approach to evolving a solution.

Q What is the correct approach?

A There isn't one yet; or, rather, there are several seat-of-the pants approaches, and although they describe a straightforward method of performing the initial design, they do not address system tuning or modification.

Don't think of this drawback a reason not to use a fuzzy approach; instead, consider it a reason to use fuzzy logic with caution.

Q What are some of the disadvantages of fuzzy systems?

A I've mentioned a couple already: There is no formal design method, and we still do not have good metrics and cannot say for sure when to use fuzzy logic and how much better it will be than using traditional methods.

An additional—and well publicized—drawback is that the resulting system is not analytic, and, in general, you cannot prove the system's stability on paper.

But we're getting there. You can apply some traditional nonlinear system analysis to some fuzzy systems. The few designers who do such analysis are those who design critical systems, such as aircraft-control systems.

But we need to take a step back here. Fuzzy logic was developed for complex systems for which designers could not create mathematical models or whose models were gross simplifications. A traditional control system either will not work at all or will work marginally for such systems. Any stability analysis of these complex systems will only poorly represent the actual functioning system.

What's the solution? First, don't let the fact that fuzzy systems are not analytic keep you from using one for a task it can easily do. Second, simulate the heck out of the system design.

Q What are the advantages of fuzzy logic?

A Fuzzy logic lets you implement systems too complex, too nonlinear, or with too much uncertainty to implement using traditional techniques. It also lets you implement and modify systems more quickly and squeeze additional capability from existing designs.

Q What country leads in the application of fuzzy logic to practical systems?

A The numbers bandied about among those "in the know" are that Japan is five to ten years ahead of the US and that Europe (or at least Germany and Italy) is one year ahead of the US. The cost of lagging behind is difficult to ascertain, but it will probably be

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evident in sales of systems that use fuzzy logic and outperform their competition.

Q If using fuzzy logic is worthwhile, what will it take for industries to use it?

A This movement is happening already. More and more forward-looking companies are finding fuzzy solutions to current problems. These companies and those that already have fuzzy systems will be the competition that will motivate other companies to test the water.

One more point: From the number of telephone calls I get weekly, I would say it is a rare US technical company with more than 200 employees that doesn't have at least one knowledgeable engineer enthused about applying fuzzy logic. Unfortunately, this enthusiasm has not yet bubbled up through the corporate structure to those that control the purse strings. EDN

Author's biography

David Brubaker is president of The Huntington Group (Menlo Park, CA, (415) 325-7554), consultants in the design of systems using real-time embedded processors and fuzzy logic. He has worked with Sun Microsystems, Beckman Instruments, Motorola, TRW, Ford, and ESL. David holds BS, MS, and PhD degrees in electrical engineering from Stanford University (Stanford, CA). His hobbies include walking, backpacking, and coaching his children's basketball teams.

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